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THE EFFECT OF SHADING ON THE TRANSPIRATION AND ASSIMILATION OF THE TOBACCO PLANT IN CUBA

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(WITH ONE FIGURE)

Introduction

This paper gives an account of experiments conducted in Western Cuba for the purpose of determining the effect on transpiration and assimilation in the tobacco plant of the cheese-cloth shade which is frequently used in that region for shading tobacco. A comparative study of the transpiration and assimilation of the tobacco plant under normal conditions and under the conditions induced by cheese-cloth shading is of interest for several reasons. First, although investigations[1] of the influence of different light intensities on transpiration have nearly always led to the conclusion that the rate of transpiration is decreased with a lessening illumination, the experiments which have established this conclusion have necessarily been conducted with plants or parts of plants which could be kept under observation only for short periods of time, and often under laboratory conditions. Data permitting a comparison of the transpiration of plants under normal conditions with others of the same kind shaded during their entire development are not at

[1] KOHL, G., Die Transpiration der Pflanzen, etc. pp. 52–74. 1886; BURGERSTEIN, A., Die Transpiration der Pflanzen. pp. 85–103. 1904; LIVINGSTON, B. E., Light intensity and transpiration. BOT. GAZ. 52:417–438. 1911.

hand.[2] Second, in view of the fact that a large portion of the tobacco crop is grown regularly under shade, such data would not be devoid of practical interest, especially in regions like Western Cuba, where annual crops require irrigation and where much of the irrigation is accomplished by toilsome hand labor. Finally, in the minds of investigators, transpiration has frequently been associated with assimilation. The water requirement of agricultural crops has usually been stated in a ratio of the quantity of water transpired to dry substance produced. As a rule, this ratio has been considered merely as a convenient empirical expression of the water-utilization of plants; but some writers have assumed a closer relation and have postulated a direct influence of transpiration on production, or conversely. Therefore, it is of interest to determine to what extent the conditions induced by shade, either directly or through their influence on transpiration, affect production.

For these reasons, the work described in the following pages was undertaken at the Cuban Agricultural Experiment Station at Santiago de las Vegas during the season of 1908–1909. For constant and ready aid in carrying out the exacting work required for this investigation, I am much indebted to ENRIQUE IBAÑEZ and AUGUSTIN GARCIA, at that time my assistants at the station.

Environment

GENERAL STATEMENT

For the purpose of these experiments, six tobacco plants were grown in the open ground, and six under cheese-cloth shade in a manner described later. The cheese-cloth was of the kind generally used in Cuba and elsewhere for shading tobacco (fig. 1). During the middle of the day, when the sun's rays are nearly perpendicular, this cloth casts a barely perceptible shadow, which, however, is more noticeable early in the morning or late in the afternoon. In

[2] FITTBOGEN indeed grew to maturity some plants of oats in a greenhouse and others in the open. He regarded the loss of light due to its passage through the glass as one of the factors tending to lower the transpiration of the plants. This experiment, however, can hardly be classed as a study of the effect of shading on transpiration. FITTBOGEN, J., Über Wasserverdunstung der Haferpflanze unter verschiedenen Wärme-, Licht-, und Luftfeuchtigkeits-Verhältnissen. Landw. Jahrb. 3:141–146. 1874.

order to determine the effect of the cheese-cloth on the environment of the plants, measurements were made during the course of the experiments of the various environmental factors both under the

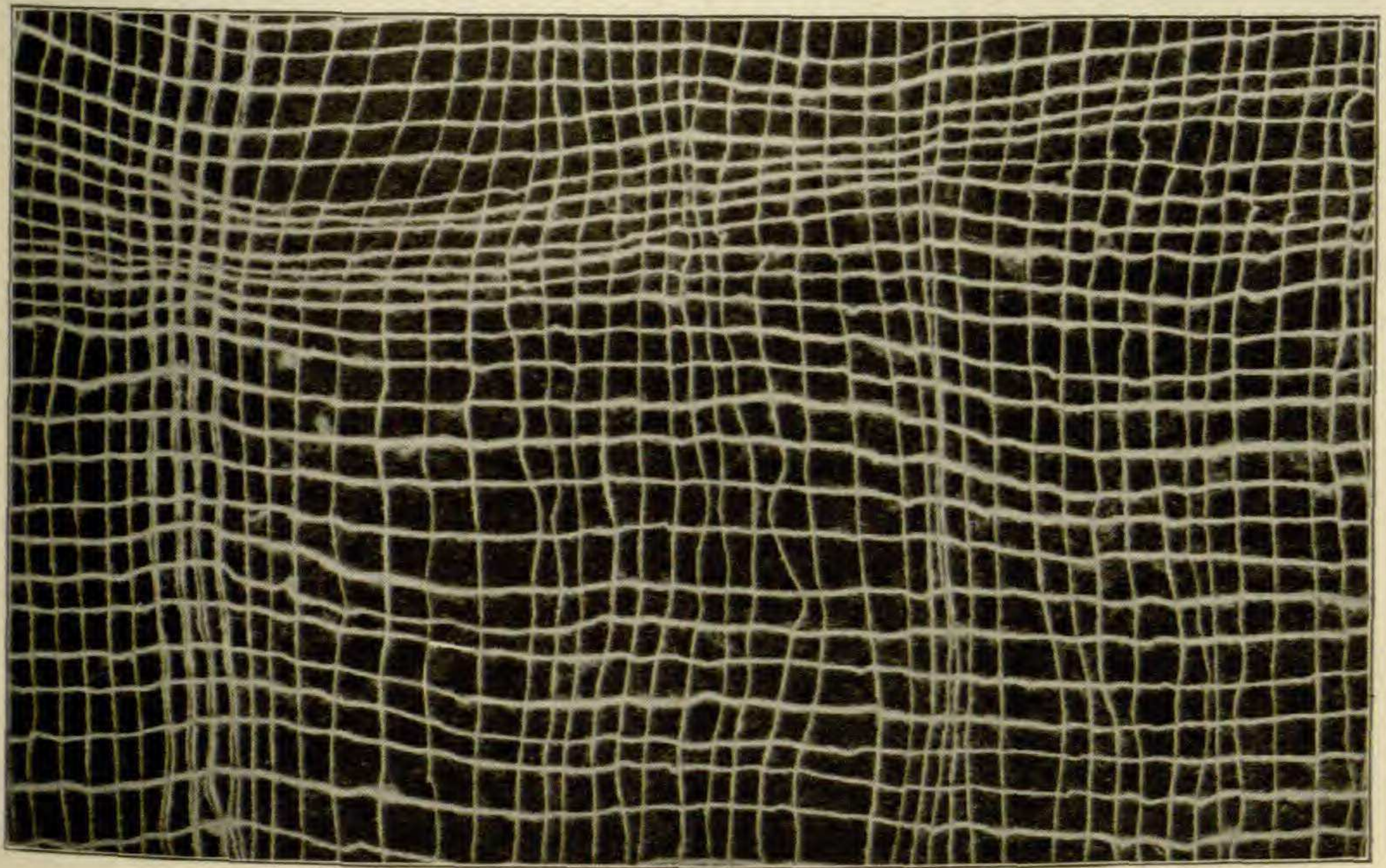

FIG. 1.—Photograph of the cheese-cloth used in the experiments; natural size

cheese-cloth and in the open. The results of these measurements are given in the following paragraphs.

LIGHT

The light intensity under the two conditions was measured by the photometric method. The method in general was that described by WIESNER[3] and used by him in his extensive researches on the light relations of plants. However, owing to the difficulty of making a sensitive paper which at some stage in the process of darkening would exactly match the normal tint kindly sent the writer by Professor WIESNER, a standard instrument, the Wynne exposure-meter, was used in these observations. The time of exposure was measured by means of a stop-watch. The applicability of this method, as well as its shortcomings, have been fully discussed by WIESNER and others, and recently LIVINGSTON[4] has subjected

[3] WIESNER, J., Der Lichtgenuss der Pflanzen. pp. 10–33. 1907.

[4] LIVINGSTON, *loc. cit.*

to a critical comparison this and other methods of measurement of solar energy. These discussions need not be repeated here. In spite of the shortcomings of this method, it has the advantage of being capable of easy manipulation and gives sufficiently correct results for a comparison of relative light values under the cheese-cloth shade and in the open.

The observations were taken on December 12, December 23, and January 25. December 12 and January 25 were bright days with only a few hazy clouds, which are usual in Cuba toward the middle of the day. December 23 was cloudy, so that all the light on that day was diffuse. On the first day, December 12, ten observations were taken usually at each hour period for each kind of light under each condition, but on account of the length of time required to make that number of observations and the change of light meanwhile, only five observations were taken at each reading on the other days. As a rule, the observations were taken alternately within and without the tent. Since the personal equation in the judgment of color is likely to play an important part in determining the time required for the sensitive paper to reach a standard tint, the probable error of the average was calculated for each set of observations, except some taken early or late in the day, when, on account of the weakness of the light, it was not possible in some cases to take more than one or two observations. An examination of the probable errors given with the column of averages shows that it is not of undue magnitude. It may also be stated that the ten or five observations from which the average is made up showed a very close agreement, usually within a fraction of a second of each other except when the exposures were very long, that is, 30 seconds or more, although, as has been stated, the observations were taken alternately in the two stations in such a way that the observer was not influenced by the previous observation and record. From the observations thus made each hour in each station, the average time of exposure was calculated. These averages with their probable errors are given in table I.

The light intensity is of course proportional to the reciprocal of the time of exposure. These reciprocals were obtained, therefore, but in order to reduce the figures of each day to relative values, the highest light intensity for each day was assigned the value of 10, and the other values were reduced to the same basis. These figures are given in table II. The relative light values for any one day, therefore, are all directly comparable, but the figures for one

TABLE I

AVERAGE LENGTHS (IN SECONDS) OF EXPOSURES MADE IN DETERMINING LIGHT VALUES

Time of exposure	Open		Shade	
	Total light	Diffuse light	Total light	Diffuse light
December 12				
8:15– 8:30 A.M.	5.33±0.12	10.66±0.10	8.72±0.10	12.13±0.25
9:15– 9:30 A.M.	3.56±0.07	6.90±0.13	6.22±0.11	9.72±0.13
10:00–10:15 A.M.	2.92±0.09	7.58±0.18	4.36±0.10	7.31±0.11
11:00–11:15 A.M.	2.23±0.05	8.26±0.13	3.29±0.02	9.32±0.12
12:30– 1:00 P.M.	2.32±0.06	7.55±0.13	3.06±0.11	9.29±0.10
1:30– 2:00 P.M.	3.58±0.07	9.67±0.10	5.13±0.07	10.48±0.21
2:30– 3:00 P.M.	5.16±0.11	12.30±0.23	7.14±0.19	10.33±0.12
3:30– 4:00 P.M.	8.70±0.18	17.26±0.18	11.34±0.12	15.48±0.34
4:45– 5:15 P.M.	24.32±0.95	60.00	134.30	....
December 23				
7:00 A.M.	....	33.07±0.86	....	56.33±1.03
8:00 A.M.	....	10.68±0.89	....	15.68±0.57
9:00 A.M.	....	6.46±0.12	....	9.23±0.49
10:00 A.M.	....	7.72±0.18	....	12.52±0.12
11:00 A.M.	....	6.76±0.41	....	8.80±0.50
12:00 M.	....	10.68±0.17	....	13.66±0.18
1:00 P.M.	....	5.14±0.08	....	7.84±0.08
2:00 P.M.	....	6.34±0.16	....	8.44±0.08
3:00 P.M.	....	6.96±0.08	....	10.56±0.11
4:00 P.M.	....	14.36±0.28	....	21.40±0.34
5:00 P.M.	....	87.50±3.04	....	94.00±0.67
January 25				
7:00 A.M.	59.50±2.36	....	71.00±4.05	....
8:00 A.M.	8.80±0.06	....	13.65±0.10	....
9:00 A.M.	3.60±0.07	8.48±0.08	7.12±0.12	11.20±0.10
10:00 A.M.	3.00±0.06	10.32±0.14	6.32±0.10	11.60±0.20
11:00 A.M.	2.34±0.09	6.88±0.16	4.76±0.11	7.82±0.07
12:00 M.	2.04±0.05	6.92±0.16	3.60±0.08	8.16±0.08
1:00 P.M.	2.48±0.05	7.68±0.09	4.00±0.06	8.56±0.16
2:00 P.M.	3.52±0.08	10.08±0.12	5.44±0.10	11.35±0.17
3:00 P.M.	5.60±0.21	13.12±0.29	8.12±0.09	14.68±0.22
4:00 P.M.	7.20±0.09	20.00±0.30	18.48±0.26	....

day are not directly comparable with those of another day, since for each day a different number was taken as the unit. This system was adopted since it was not the purpose to compare the light values of the different days, but only those within the cheese-cloth tent with those outside.

From table II the following conclusions may be drawn: On the bright days (December 12 and January 25) the total light within the tent was 30–40 per cent, or about one-third, less than that without, but the diffuse light showed very little difference in the two stations on those days. On December 23, however, when there was no bright sun, the total light in the tent (all diffuse) was reduced by about one-third. On the bright days the ratio of diffuse light to total light was much higher in the tent than in the open. The

TABLE II

RELATIVE LIGHT VALUES UNDER CHEESE-CLOTH SHADE AND IN THE OPEN

TIME OF OBSERVATION	TOTAL LIGHT		DIFFUSE LIGHT		RATIO DIFFUSE/TOTAL	
	Open	Shade	Open	Shade	Open	Shade
December 12						
8:15– 8:30 A.M.	4.2	2.5	2.1	1.8	0.50	0.72
9:15– 9:30 A.M.	6.3	3.6	3.2	2.3	0.51	0.64
10:00–10:15 A.M.	7.6	5.1	2.9	3.0	0.38	0.59
11:00–11:15 A.M.	10.0	6.8	2.7	2.4	0.27	0.35
12:30– 1:00 P.M.	9.6	7.3	2.9	2.4	0.30	0.33
1:30– 2:00 P.M.	6.2	4.3	2.3	2.1	0.37	0.49
2:30– 3:00 P.M.	4.3	3.1	1.8	2.2	0.42	0.71
3:30– 4:00 P.M.	2.5	2.0	1.3	1.4	0.52	0.70
4:45– 5:15 P.M.	0.9	0.2	0.4	....	0.44	....
December 23						
7:00 A.M.	....	....	1.6	0.9	....	....
8.00 A.M.	....	....	4.8	3.3	....	....
9:00 A.M.	....	....	7.9	5.6	....	....
10:00 A.M.	....	....	6.7	4.1	....	....
11:00 A.M.	....	....	7.6	5.8	....	....
12:00 M.	....	....	4.8	3.8	....	....
1:00 P.M.	....	....	10.0	6.5	....	....
2:00 P.M.	....	....	8.1	6.1	....	....
3:00 P.M.	....	....	7.4	4.9	....	....
4:00 P.M.	....	....	3.6	2.4	....	....
5:00 P.M.	....	....	0.6	0.5	....	....
January 25						
7:00 A.M.	0.3	0.3	....	....	....	....
8:00 A.M.	2.3	1.5	....	....	....	....
9:00 A.M.	5.7	2.9	2.4	1.8	0.42	0.62
10:00 A.M.	6.8	3.2	2.0	1.8	0.29	0.56
11:00 A.M.	8.7	4.3	3.0	2.6	0.34	0.60
12:00 M.	10.0	5.7	2.9	2.5	0.29	0.44
1:00 P.M.	8.2	5.1	2.7	2.4	0.33	0.47
2:00 P.M.	5.8	3.7	2.0	1.8	0.34	0.49
3:00 P.M.	3.6	2.5	1.6	1.4	0.44	0.56
4:00 P.M.	2.8	1.1	1.0	....	0.36	....

effect of the cheese-cloth tent, therefore, appears to be not only to reduce the total amount of light available to the plants, but also to transform a large proportion of the direct light into diffuse light. The plants growing within the tent have available for photosynthesis less total light than the plants growing outside, but a larger proportion of this light is diffuse.

TEMPERATURE

The temperatures in each of the two stations were recorded by Fries thermographs placed in shelters so constructed, with double roof and open sides, as to protect the instruments from the direct rays of the sun and from rain without hindering the free circulation of air. The thermographs had been carefully adjusted during a few weeks' trial previous to the beginning of the experiments. After having been placed in the field, they were daily compared with standard thermometers whose bulbs hung near the bellows of the instruments. The thermographs agreed very closely with the thermometers throughout the experiment, and required very little further adjustment.

The average daily temperatures during the course of the experiment were obtained by integrating the records for each day with a planimeter. The results thus obtained, together with the differences between the daily average in the tent and in the open, are given in table III. The records are given in Fahrenheit degrees since the instruments recorded in that scale, but the values have also been calculated in Centigrade degrees, which are given in the last two columns.

Table III shows that there was no marked difference between the temperature within the tent and that outside. The difference was usually less than one degree. Moreover, it was sometimes positive and sometimes negative. The sum of the differences for the total period is only 7°67 F. The average daily excess of the temperature outside the tent over that inside was therefore approximately 0°14. This is contrary to the results of STEWART,[5] who found that in the Connecticut Valley the average daily temperature

[5] STEWART, J. B., The effects of shading on soil conditions. U.S. Dept. Agric., Bureau of Soils, Bull. 39. 1907.

TABLE III

AVERAGE DAILY TEMPERATURE

For 24 hours ending at 4 P.M.	Mean temperature (Fahrenheit)		Difference	Mean temperature (Centigrade)	
	Open	Shade		Open	Shade
December 4	72.23	....	....	22.35	....
" 5	69.54	70.91	+1.37	20.86	21.62
" 6	75.35	76.14	+0.79	24.08	24.52
" 7	74.54	73.93	−0.61	23.63	23.29
" 8	68.52	69.03	+0.51	20.29	20.57
" 9	71.67	71.12	−0.55	22.04	21.73
" 10	69.68	68.77	−0.91	20.93	20.43
" 11	64.86	61.90	−2.96	18.26	16.61
" 12	62.86	63.56	+0.70	17.14	17.53
" 13	67.03	66.55	−0.48	19.46	19.19
" 14	64.46	64.86	+0.40	18.03	18.25
" 15	67.02	68.13	+1.11	19.46	20.07
" 16	66.85	67.74	+0.89	19.36	19.85
" 17	67.26	68.53	+1.27	19.59	20.29
" 18	64.68	67.40	+2.72	18.16	19.67
" 19	69.00	69.82	+0.82	20.56	21.01
" 20	71.17	72.05	+0.88	21.76	22.25
" 21	67.75	67.60	−0.15	19.86	19.78
" 22	68.90	70.55	+1.65	20.50	21.42
" 23	67.06	67.43	+0.37	19.48	19.68
" 24	65.04	65.10	+0.06	18.36	18.39
" 25	65.34	64.95	−0.39	18.52	18.30
" 26	63.42	63.54	+0.12	17.46	17.52
" 27	58.30	58.45	+0.15	14.61	14.69
" 28	65.76	65.25	−0.51	18.76	18.47
" 29	67.94	67.62	−0.32	19.97	19.79
" 30	72.85	70.51	−2.34	22.69	21.39
" 31	72.00	70.86	−1.14	22.22	21.59
January 1	69.68	68.04	−1.64	20.93	20.02
" 2	68.23	68.01	−0.22	20.13	20.01
" 3	72.13	71.02	−1.11	22.29	21.68
" 4	73.81	72.81	−1.00	23.23	22.67
" 5	72.28	71.78	−0.50	22.38	22.10
" 6	68.62	68.47	−0.15	20.34	20.26
" 7	63.29	62.17	−1.12	17.38	16.76
" 8	62.69	61.39	−1.30	17.05	16.33
" 9	66.67	65.28	−1.39	19.26	18.49
" 10	66.58	66.64	+0.06	19.21	19.24
" 11	65.07	64.80	−0.27	18.37	18.22
" 12	66.89	66.60	−0.29	19.38	19.22
" 13	65.69	65.14	−0.55	18.72	18.41
" 14	71.80	69.51	−2.29	22.11	20.84
" 15	67.50	65.73	−1.77	19.72	18.74
" 16	67.42	67.09	−0.33	19.68	19.49
" 17	65.33	64.13	−1.20	18.52	17.85
" 18	63.84	63.45	−0.39	17.69	17.47
" 19	65.58	67.00	+1.42	18.66	19.44
" 20	66.40	66.37	−0.03	19.11	19.09
" 21	65.96	65.18	−0.78	18.87	17.88

TABLE III—*Continued*

For 24 hours ending at 4 P.M.	Mean temperature (Fahrenheit)		Difference	Mean temperature (Centigrade)	
	Open	Shade		Open	Shade
January 22.....	71.24	70.24	−1.00	21.80	21.24
" 23.....	68.05	68.57	+0.52	20.03	20.32
" 24.....	65.98	66.87	+0.89	18.88	19.37
" 25.....	66.35	66.22	−0.13	19.08	19.01
" 26.....	62.58	64.40	+1.82	16.99	18.00
" 27.....	63.13	64.10	+0.97	17.29	17.83
" 28.....	60.20	60.86	+0.66	15.67	16.03

within a cheese-cloth tent was 1–3° F. higher than that outside. It is possible that the climatic conditions in these two regions are sufficiently different to account for the apparently different effects of the cheese-cloth, but it should be stated that STEWART obtained his average daily temperature from the maximum and minimum temperatures of each day, a method which does not give the true average temperature. It is evident from the data of table III that under the climatic conditions prevailing in Western Cuba during the months of December and January the cheese-cloth tents used for shading tobacco in that region show very little tendency to retain heat.

Relative humidity

The relative humidity in the two stations was recorded by means of Draper hygrometers. These instruments, like the thermographs, had been kept under observation for several weeks previous to the beginning of the experiments, and during that time had been adjusted to correspond through the lower part of their range with a sling psychrometer. Since the range of these instruments was not adjustable, it was not possible to make them correspond with the psychrometer readings through the whole range of the scale. At night, when the sling psychrometer regularly showed a relative humidity of 100 per cent, the hygrometers still showed a deficit of 4–5 per cent. The recording instruments, however, agreed with each other throughout the range of the movement of the pens. Each week during the course of the experiment the instruments were compared by being placed side by side for one hour. They

TABLE IV

AVERAGE DAILY HUMIDITY

For 24 hours ending 4 P.M.	Hygrometer			Sling psychrometer		
	Open	Shade	Difference	Open	Shade	Difference
December 1	79.5	79.0	−0.5	....	....	....
" 2	78.5	79.5	+1.0	....	....	....
" 3	79.5	80.0	+0.5	....	....	....
" 4	79.5	80.0	+0.5	....	....	....
" 5	84.5	84.0	−0.5	....	....	....
" 6	78.5	79.0	+0.5	....	....	....
" 7	78.0	78.5	+0.5	....	....	....
" 8	81.0	82.0	+1.0	....	....	....
" 9	81.5	84.0	+2.5	....	....	....
" 10	83.0	85.5	+2.5	86.0	83.6	−2.4
" 11	74.0	77.0	+3.0	46.2	49.0	+2.8
" 12	79.5	81.5	+2.0	47.4	48.6	+1.2
" 13	89.0	91.0	+2.0	86.0	88.6	+2.6
" 14	79.5	82.5	+3.0	49.6	51.4	+1.8
" 15	79.5	83.0	+3.5	51.6	57.4	+5.8
" 16	84.5	86.5	+2.0	59.4	61.6	+2.2
" 17	79.5	81.5	+2.0	53.0	56.8	+3.8
" 18	76.0	77.0	+1.0	46.0	46.6	+0.6
" 19	75.0	78.0	+3.0	44.6	44.8	+0.2
" 20	78.5	78.5	....	49.0	49.0	....
" 21	80.0	80.5	+0.5	56.2	54.0	−2.2
" 22	86.0	84.5	−1.5	51.2	53.2	+2.0
" 23	85.5	86.5	+1.0	73.8	73.4	−0.4
" 24	77.5	78.5	+1.0	46.4	47.6	+1.2
" 25	82.5	83.0	+0.5	63.4	63.0	−0.4
" 26	78.0	80.0	+2.0	56.8	61.4	+4.6
" 27	78.0	79.5	+1.5	50.6	52.2	+1.6
" 28	71.0	73.5	+2.5	43.0	44.0	+1.0
" 29	71.0	73.0	+2.0	49.6	52.4	+2.8
" 30	81.0	83.0	+2.0	66.4	70.2	+3.8
" 31	86.0	85.5	−0.5	75.4	77.4	+2.0
January 1	86.5	86.0	−0.5	78.0	79.2	+1.2
" 2	84.0	84.0	....	62.4	62.4	....
" 3	82.0	82.0	....	64.0	68.4	+4.4
" 4	81.5	83.0	+1.5	64.0	63.6	−0.4
" 5	87.5	88.5	+1.0	73.2	73.8	+0.6
" 6	79.5	81.0	+1.5	57.8	57.8	....
" 7	78.0	80.0	+2.0	61.4	63.4	+2.0
" 8	81.0	83.0	+2.0	65.6	71.2	+5.6
" 9	85.5	87.5	+2.0	78.4	78.8	+0.4
" 10	74.5	79.5	+5.0	47.4	54.0	+6.6
" 11	74.0	77.0	+3.0	45.8	54.4	+8.6
" 12	70.0	74.0	+4.0	43.0	50.2	+7.2
" 13	71.5	77.0	+5.5	42.4	48.4	+6.0
" 14	75.0	78.5	+3.5	55.6	59.6	+4.0
" 15	78.0	83.0	+5.0	65.2	70.6	+5.4
" 16	77.5	81.5	+4.0	58.2	58.4	+0.2
" 17	77.5	80.5	+3.0	60.4	66.2	+5.8
" 18	83.0	86.0	+3.0	67.0	69.4	+2.4
" 19	77.5	82.0	+4.5	46.0	50.2	+4.2
" 20	77.0	80.5	+3.5	53.6	63.2	+9.6

TABLE IV—*Continued*

For 24 hours ending 4 P.M.	Hygrometer			Sling psychrometer		
	Open	Shade	Difference	Open	Shade	Difference
January 21........	77.0	80.5	+3.5	50.8	57.8	+7.0
" 22........	76.5	80.0	+3.5	48.4	58.2	+9.8
" 23........	80.0	83.0	+3.0	57.2	66.4	+9.2
" 24........	78.5	82.5	+4.0	58.2	62.8	+4.6
" 25........	76.0	80.0	+4.0	50.2	54.4	+4.2
" 26........	77.0	80.5	+3.5	52.0	60.0	+8.0
" 27........	77.0	80.0	+3.0	53.8	56.8	+3.0
" 28........	74.0	78.5	+4.5	50.0	54.8	+4.8

were readjusted only once during the entire time. To overcome the effects of accidental differences not detected the hygrometers of the two stations were interchanged each week. From what has been said it will be clear that only a relative value can be ascribed to the humidity records. Since the two instruments agreed with each other when kept under the same conditions, this record, nevertheless, ought to give a fair idea of the differences in relative humidity inside and outside the tent. The daily averages were obtained by integrating the curves of the records (which are on circular charts) by means of a Bristol-Durand radii-averaging instrument. These averages, together with the differences between the figures for the two stations for each day, are given in table IV. In addition to the hygrometer records, daily observations were taken at noon in the two stations by means of a sling psychrometer. The results of these observations are given in the fourth and fifth columns of the table, where each figure represents the average of five readings. These observations taken at noon represent approximately the lowest relative humidity for each day.

Table IV shows that the relative humidity is higher inside than outside the tent, but the difference is not as great as that found by STEWART in Connecticut. Owing to the greater quantities of water given off by the plants with increase in leaf surface during growth, the difference is greater toward the end of the season than at the beginning. This relation is brought out still more strikingly by the differences during the day, when the plants are actively transpiring. The difference in the relative humidity inside and outside the tent at noon is much greater than the difference in the average relative humidity of the two stations.

Evaporation

Records of the relative rates of evaporation in the two stations were obtained by means of the porous cup atmometer described by LIVINGSTON[6] and since frequently used in studies dealing with the relation between plant functions and meteorological conditions.

TABLE V

EVAPORATION FROM POROUS CUP ATMOMETERS

Date	Open	Shade	Date	Open	Shade
December 2	19.9 cc.	15.5 cc.	December 31	9.7 cc.	4.2 cc.
" 3	16.4	12.4	January 1	8.1	4.3
" 4	10.8	10.0	" 2	12.6	6.5
" 5	12.7	9.2	" 3	12.2	7.8
" 6	22.5	16.2	" 4	12.0	6.4
" 7	18.2	12.8	" 5	5.5	1.8
" 8	15.6	12.0	" 6	13.6	8.3
" 9	14.4	10.6	" 7	14.1	6.8
" 10	15.6	11.3	" 8	12.5	6.0
" 11	22.3	16.4	" 9	6.2	2.4
" 12	17.0	12.6	" 10	18.5	8.5
" 13	1.4	0.0	" 11	19.8	8.5
" 14	14.8	10.7	" 12	22.7	10.0
" 15	18.3	13.5	" 13	19.4	8.1
" 16	14.1	10.8	" 14	21.3	9.3
" 17	21.0	15.2	" 15	15.5	6.2
" 18	25.2	16.7	" 16	13.8	5.9
" 19	22.1	16.0	" 17	14.8	5.7
" 20	22.1	15.7	" 18	6.8	1.7
" 21	16.6	12.1	" 19	13.6	5.4
" 22	13.8	9.5	" 20	14.4	5.7
" 23	11.7	7.0	" 21	14.6	6.1
" 24	20.2	13.3	" 22	15.8	7.1
" 25	16.3	11.1	" 23	13.8	6.1
" 26	20.7	12.3	" 24	12.8	6.0
" 27	21.1	13.3	" 25	15.3	7.4
" 28	30.3	18.3	" 26	13.8	6.6
" 29	16.4	16.8	" 27	13.8	6.2
" 30	13.0	8.0	" 28	14.4	6.6
Total				905.9	540.9

The instruments were set up in such a manner that the cups were about one meter above the ground, the water being supplied to the cups by means of burettes. With the growth of the surrounding plants the cups were partly shaded, but this was not considered

[6] LIVINGSTON, B. E., A simple atmometer. Science N.S. 28:319, 320. 1908; see also Plant World 15:157–162. 1912.

disadvantageous, since the cups were thus probably exposed to nearly the same average conditions of light and shade as the leaves. The record of evaporation from the cups during the course of the experiments is given in table V. The figures are all reduced to terms of evaporation from a standard atmometer whose coefficient is taken as unity. They are directly comparable, therefore, with each other and with the figures given by LIVINGSTON[7] and by CALDWELL.[8]

Table V shows that the rate of evaporation is constantly less under the cheese-cloth cover than it is in the open. As with the relative humidity, the difference between the two stations increases with the development of the plants. During the early part of the period covered by the experiments, the cups in the open lost one-fourth to one-third more water than those in the shade, but later the loss from the cups in the open was more than twice that from those in the shade. The increasing divergence of the rates of evaporation corresponds with the increasing quantity of water vapor given off by the growing plants.

Rainfall

As a rule, there is very little rainfall in Western Cuba in the winter months, during which the tobacco crop is grown, consequently tobacco and other crops grown during that season require irrigation. The season during which this experiment was conducted was no exception. The only rather heavy rains occurred on December 13 and December 15, and on January 5. The complete record of rainfall taken from the weather observations at the station during the time of the experiment is as follows:

December	2.....	3.30 mm.	January	1......	1.02 mm.
"	8.....	3.81 "	"	2......	0.76 "
"	13.....	11.68 "	"	4......	1.02 "
"	15.....	7.37 "	"	5......	12.58 "
"	30.....	1.78 "	"	8......	1.52 "
"	31.....	1.02 "	"	19......	0.51 "

[7] LIVINGSTON, B. E., A study of the relation between summer evaporation intensity and centers of plant distribution in the United States. Plant World 14:205–222. 1911.

[8] CALDWELL, J. S., The relation of environmental conditions to the phenomena of permanent wilting in plants. Physiol. Researches 1:1–56. 1913.

Summary of observations on environment

The data relating to the changes in the environment induced by the cheese-cloth shade may be briefly summed up here.

The light intensity is greatly modified by the cheese-cloth shade. The total light under the cloth is reduced by about one-third, but the diffuse light inside the tent is only slightly reduced. It appears, therefore, that the plants inside the tent receive a smaller quantity of total light than the plants outside, but an almost equal amount of diffuse light.

The cheese-cloth tent shows very little effect on the temperature. On the whole, the temperature outside the tent is slightly higher than that inside. The average difference for the 60 days, however, is only about 0°14 F. This can have but little effect on the transpiration of the plants. It appears that any tendency of the tent to retain heat is compensated by the reduced amount of radiant energy which passes into the tent.

The difference in the relative humidity of the two stations is much greater than the difference in temperature. This difference is restricted to the hours of sunlight, for at night the relative humidity in both stations reaches 100 per cent. During the day the difference is enhanced by the partial retention by the tent of the water transpired by the plant.

The rate of physical evaporation is greater in the open than under the cheese-cloth shade. The divergence of the rates of evaporation in the two stations increases with the development of the plants and the consequent increase in relative humidity under the cheese-cloth.

Aside from the lessening of the illumination and the increase in relative humidity, the cheese-cloth effects a reduction of air currents. All these changes tend to diminish transpiration.

Materials and methods of experimentation

The plants used in this work were grown from seed obtained during the previous season from a single self-fertilized mother-plant, whose offspring was shown by subsequent cultivation both in Cuba and in the United States to be of a pure strain.[9] From a

[9] The strain used was the no. 7 described in the following paper: HASSELBRING, H., Types of Cuban tobacco. BOT. GAZ. 53:113–126. *pls. 4–10.* 1912.

large number of seedlings, 12 were selected as uniform as possible. The experimental plants were grown in cylindrical galvanized iron tanks 38 cm. high and 30.5 cm. in diameter. These tanks resembled in general construction those described by FORTIER.[10] Each tank was provided with an inlet tube 1.3 cm. in diameter, which ran down the inside of the tank to the center of the bottom where it ended. The upper end of the tube was closed by a screw cap. Each tank was further provided at the rim with two lugs into which hooks could be inserted to facilitate lifting and carrying the tanks. These tanks were fitted into others just large enough to receive them, which were permanently sunk in the ground. To prevent the soil from falling into the space between the walls of the two tanks, the inner tanks were provided near the rim with annular flanges which projected over the rims of the outer tanks. In order to prevent rain water from reaching the soil in the tanks, they were fitted with covers made in two parts, with flanges interlocking in such a way that water could enter only through the opening around the stem of the plant. This was closed as effectually as possible by means of thin sheet rubber. The covers were placed on the tanks every night and during threatening weather.

The soil used for filling the tanks was taken from a well-tilled field which in former years had been used for growing tobacco and other crops. A quantity, somewhat more than sufficient for filling the tanks, was placed on the concrete floor of a closed shed, where it was thoroughly worked over many times, with the addition of successive small quantities of water until the whole mass was brought into a moist, friable condition. The soil was left in a pile for a day to allow the moisture to become uniformly distributed throughout the mass. On the following day it was again worked over several times and run through a screen preparatory to the filling of the tanks.

Before the tanks were filled, a layer of broken stone was placed on the bottom of each in order to form a sort of reservoir for water and to prevent the closing of the inlet tube by the soil. By means of the stones the tanks were all brought to the same tare. They were then filled with soil which was tamped as uniformly as possible

[10] FORTIER, S., Evaporation losses in irrigation and water requirements of crops. U.S. Dept. Agric., Office of Exp. Stations, Bull. 177. 1907.

to give it the same compactness as the soil of the field. Thirty kilograms of soil were put into each can.

The seedlings which had 3 or 4 small leaves were planted in the tanks on November 27, 1908. At that time each plant was given 500 cc. of water at the surface, and 1000 cc. were added to each tank through the inlet tube. The tanks were left under cover of the shed until the following day (November 28), when all the plants had completely recovered from the effects of transplanting. The tanks were then given another liter of water through the inlet tube and enough more was added to those that required it to bring them all to the same weight.

One set of six tanks with plants, and three without plants that had been treated in every way like those containing plants, was placed in two rows among the plants of the regular crop under the cheese-cloth which covered an area of one hectare (2.471 acres). The other similar set was placed in like manner in an adjoining field of one hectare also planted with tobacco. The sets of experimental plants were thus subjected to the same conditions in their respective environments as the plants of the regular crop.

The general development of the experimental plants was in every way normal, and did not differ from that of those among which they stood. The axillary buds were removed as soon as they appeared, so that the plants grew to a single stem without branches. The terminal buds were not removed, however, as is customary in commercial practice.

The shade plants attained a nearly uniform height of 2.1 meters, while the height of the sun plants, which were a little less uniform, averaged about 1.75 meters. The leaves of the shade plants were much larger and thinner than those of the sun plants and the internodes of the stems were longer.

During the course of the experiment the original seedling leaves, which had increased much in size, withered. These were cut off and dried and later were ground up with the rest of the plants from which they had been taken.

In spite of the tamping of the soil in the tanks, it was found that the soil water receded from the upper layers of soil, which became very dry. Whenever this condition led to incipient wilting, the proper state of moisture was restored by adding measured quantities of water at the surface, the controls being treated in the same way. In all, five liters of water were thus added from November 27 to January 14.

From the time that the tanks were placed in the field, the loss of water from the soil and plants was determined by daily weighings. For these weighings a small platform scale specially constructed for the purpose was used. This scale was equipped with agate bearings and with two riders which could be clamped at any point on the beams, one of which was graduated in units of one gram for the smaller rider. The end of the beam was provided with a pointer which indicated the position of exact balance. The scale was sensitive to one gram with the load of 35 kilograms, approximately the weight of the tanks when filled. It was placed permanently on a low solid platform in a shelter to which the tanks could be conveniently brought. The water lost from the soil and plants was replaced each day by the addition of enough water through the inlet tubes to bring the tanks up to the standard weight. While the plants were small, the quantity of water thus added was measured from a burette, but later, when the daily transpiration was large, the bulk of the water required was added by means of graduated flasks marked for pouring, only the final fractions being run in from the burette. The operation was begun at 4:00 P.M. each day and required about two hours for its completion. The quantity of water thus added was recorded as the daily loss by transpiration from the plants and evaporation from the soil.

For obtaining the total transpiration of the plants, the average quantity lost from the three control tanks was subtracted from the total quantity lost from each of the other tanks in the same station, the loss from the controls being regarued as representing the quantity lost from the soil of the tanks containing plants. The difference caused by the partial shading of the soil of the planted tanks had to be disregarded.

The plants were harvested on January 28, at about the time of maturity of the general crop. At that time the leaves were fully grown and the inflorescence was well developed, a few flowers having opened.

The leaves with their decurrent wings were first cut from each plant and weighed immediately. Thereupon, prints for determining the leaf area were made on blue-print paper. The stems, including the inflorescence, were cut off at the surface of the ground, weighed, and cut into small pieces for drying. In order to obtain the roots, the soil was washed out of the tanks with a stream of water. With the aid of a brush the roots were washed free from adhering soil particles. They were then dried by being pressed between towels and absorbent paper, weighed, and cut up for drying.

To obtain the weight of dry substance, the fresh material was dried at 60–70° C. and ground in a drug mill with the observance of such precautions that the material was quantitatively recovered. The leaves, stems, and roots of each plant were ground separately. The air-dry material thus obtained was weighed, and from each lot four samples of approximately 2 grams each were taken. These were dried to a constant weight in a slow current of hydrogen at a pressure of 6 cm. of mercury and a temperature of 78° C.

In order to make a comparison of the transpiration per unit area of leaf surface for the plants in the two stations, the leaf prints made at the time of harvesting were cut out and weighed, and their area was calculated from the relation of their weight to the weight and total area of the original paper. As a basis for calculating the transpiration per unit area of leaf surface, the average quantity of water transpired during the last five days of the experiment was taken. Since the plants had reached the flowering stage, it may be assumed that there was very little change of area of the leaves during this period. The taking of the average daily transpiration obviated to a certain extent peculiarities which might be exhibited by the transpiration of a single day.

Data

In connection with the presentation of the data, attention may again be called to the fact that the plants used in these experiments were the descendants of a single self-fertilized mother plant whose progeny was shown by subsequent cultivation during two generations to be of a pure strain. For this reason more confidence can be placed in the results than would be possible if the plants had been selected from an indiscriminate mixture. The result of this selection was manifested in the uniform growth of the plants in each of the two stations. The data relating to the total transpiration of the two sets of plants are given in table VI.

TABLE VI

WATER TRANSPIRED BY PLANTS DURING 60 DAYS OF GROWTH

Open			Shade		
No. of plant	Total water transpired	Water transpired per gram of water-free substance produced	No. of plant	Total water transpired	Water transpired per gram of water-free substance produced
1..........	51,256 cc.	245.21 cc.	10..........	41,117 cc.	194.47 cc.
3..........	41,328	245.52	12..........	37,308	187.40
5..........	45,959	239.48	14..........	35,494	192.20
6..........	44,665	237.62	15..........	33,025	191.38
7..........	45,625	246.54	16..........	32,935	176.31
9..........	44,402	235.93	18..........	31,396	180.16
Average	45,539	241.72	Average....	35,212	186.99

Table VI shows that the sun plants transpired on the average 10 liters (about 30 per cent) more water per plant than the shade plants. Although the figures show considerable fluctuation in transpiration among the individuals of each set, yet if the plants of the two sets are compared in the order of magnitude of their transpiration, it will be found that the difference between the members of the different series is practically the same as the difference between the averages for the whole series. Since the average weight of dry matter produced was the same in the two sets of plants, it follows that the series having the higher total transpiration also has the highest transpiration per gram of dry plant substance. This is substantiated by the figures which show that the shade plants transpired 186.99 cc. of water for the production of one gram of plant substance, while the sun plants transpired 241.72 cc. for one gram, or about 30 per cent more than the shade plants. The quantity of water transpired per unit of dry matter produced is remarkably uniform for the plants within each group. A similar close agreement between the quantities of water transpired per unit of dry matter produced by plants growing in different nutrient solutions has recently led MAZÉ[11] to conclude that under the same aerial conditions the quantity of water transpired per unit of dry matter produced is constant and independent of the nature of the nutritive solutions or of their concentrations or of the state of development of the plant. It is needless to state that this conclusion could hold good only for solutions which contain all the necessary nutrients and which are not otherwise injurious to the growth of plants.[12]

TABLE VII

TRANSPIRATION PER SQ. DM. OF LEAF SURFACE DURING LAST FIVE DAYS OF GROWTH

No. of plant	Leaf area in sq. cm. both surfaces	Total transpiration for last five days in cc.	Transpiration per sq. dm. of leaf surface in cc.	Average hourly transpiration per sq. dm. leaf surface in cc.
Open				
1	22,026	10,941	49.67	0.414
3	19,454	10,158	52.22	0.435
5	23,550	11,230	47.69	0.397
6	20,335	10,376	51.02	0.425
7	21,300	10,936	51.34	0.428
9	21,989	9,755	44.36	0.370
Average	21,442	10,566	....	0.412
Shade				
10	27,896	8,658	31.04	0.259
12	27,461	8,332	30.34	0.253
14	29,026	8,791	30.29	0.252
15	29,116	6,930	23.80	0.198
16	31,163	7,236	23.22	0.194
18	31,867	7,224	22.67	0.189
Average	29,442	7,862	....	0.224

The relative transpiration per unit area of leaf surface is given in table VII. As has been stated, the figures are based on the transpiration of the last five days. This table brings out the relative leaf areas of the plants grown under the two conditions. The

[11] MAZÉ, Sur la relation qui existe entre l'eau évaporée et le poids de matière végétale élaborée par le maïs. Compt. Rend. **156**:720–722. 1913.

[12] That other conditions, such as deficiency or excess of mineral nutrients, may limit production while transpiration continues has been frequently pointed out in agricultural literature: HELLRIEGEL, H., Beiträge Naturwiss. Grundlagen Ackerbaus Braunschweig. pp. 628–635; VON SEELHORST, Jour. Landw. **47**:369–378. 1899.

average leaf area per plant of those grown in the shade was 8000 sq. cm. greater than that of the plants grown in full light. Yet, as we have seen, in spite of this great difference in leaf area, the shade plants used about 10 liters of water less per plant than the sun plants. The hourly transpiration per unit of leaf surface was nearly 84 per cent greater in the plants in the open. The actual hourly transpiration was probably double that given in the tables, since the calculation was based on a 24-hour day, while the plants did not transpire perceptibly during at least 12 hours of that time. Such a change would not, however, alter the relative value of the figures which chiefly concern us here.

A comparison of the rates of transpiration from the leaves during the last five days with the rates of evaporation from the porous cups during the same period of time shows a fairly close relative agreement between transpiration and physical evaporation. The ratio of transpiration in the shade to that in the open is 1:1.8; while the ratio of evaporation from the atmometers in the two stations is 1:2.1.

The data relating to the fresh weight of the plants are given in table VIII.

TABLE VIII

FRESH WEIGHT OF PLANTS

No. of plant	Leaves	Stems	Roots	Total
Open				
1	409	364	246	1019
3	365	335	199	899
5	433	407	233	1073
6	371	388	182	941
7	412	398	197	1007
9	416	389	215	1020
Average	401	380	212	993
Shade				
10	451	508	257	1216
12	443	494	210	1147
14	467	479	193	1139
15	461	466	186	1113
16	488	483	203	1174
18	502	503	180	1185
Average	469	489	205	1162

The average weight of the shade plants was nearly 170 grams greater than that of the sun plants. Moreover, there was no aberrant case. The members within each group were fairly uniform, but all of the shade plants had a greater weight than any of the sun plants. The distribution of the material within the plants is worthy of note. Here also the results, in whatever direction they point, are true as well for a comparison of the individual plants of the respective groups with each other as for a comparison of the general averages. The average weight of the leaves of the shade plants was 68 grams higher than that of the sun plants, while the difference in the stems was still greater, the difference here being over 100 grams in favor of the shade plants. The fresh weight of the root-systems of the two groups of plants was about the same in both. These relations are especially interesting when considered in connection with the weight and distribution of dry matter in the plants as shown in table IX.

TABLE IX

WEIGHT OF WATER-FREE SUBSTANCE OF PLANTS

No. of plant	Leaves	Stems	Roots	Total
Open				
1	82.54	73.09	53.40	209.03
3	67.36	59.72	41.25	168.33
5	75.01	69.71	47.19	191.91
6	74.32	70.76	42.89	187.97
7	74.35	67.62	43.09	185.06
9	73.40	71.05	43.75	188.20
Average	74.50	68.66	45.26	188.42
Shade				
10	71.61	90.36	49.46	211.43
12	69.67	82.92	46.49	199.08
14	66.42	78.08	40.17	184.67
15	59.61	74.22	38.73	172.56
16	71.65	76.19	38.96	186.80
18	62.69	76.32	35.26	174.27
Average	66.94	79.68	41.51	188.14

While the average fresh weight of the shade plants was nearly 170 grams greater than that of the sun plants, the average dry weight of the two sets was the same, approximately 188 grams. A more marked contrast even is brought out by a comparison of the distribution of material in the different organs of the plants. The weight of dry substance in the roots was practically identical in the two groups. The stems of the shade plants contained 18 per cent more dry matter than those of the sun plants, but the leaves of the sun plants contained 11 per cent more material than the leaves of the shade plants, although the average total area of shade leaves, as shown in table VII, was 37 per cent greater than that of the sun leaves. To recapitulate, the fresh weight of the shade plants was higher than that of the sun plants. This statement applies also to the leaves and stems when the organs are considered separately, but not to the roots, which were about equal in the two sets. The average dry weight of the whole plants and of the roots was the same in the two sets of plants; but the weight of dry material in the leaves was greater for the sun plants, while that of the stems was greater for the shade plants.

These facts show that on the whole the water content of the

TABLE X

PERCENTAGE OF WATER IN LEAVES, STEMS, AND ROOTS

No. of plant	Leaves	Stems	Roots	Total
Open				
1	79.82	79.92	78.29	79.49
3	81.55	82.17	79.27	81.28
5	82.68	82.87	79.75	82.11
6	79.97	81.76	76.43	80.02
7	81.95	83.01	78.13	81.62
9	82.36	81.74	79.65	81.55
Average	81.39	81.91	78.59	81.01
Shade				
10	84.12	82.21	80.75	82.61
12	84.27	83.21	77.86	82.64
14	85.78	83.70	79.19	83.79
15	87.07	84.07	79.18	84.50
16	85.32	84.23	80.81	84.09
18	87.51	84.83	80.41	85.29
Average	85.68	83.71	79.70	83.82

shade plants was greater than that of the sun plants.[13] The figures of table X bear out this relationship, not only with regard to the plants as a whole, but also with regard to the individual organs. The complete data are given in that table.

As might be expected, the greatest difference in water content was found in the leaves, whereas the water content of the roots was about equal in the two groups. In the stems, in spite of the fact that the higher fresh weight corresponds with the higher dry weight, the shade plants, nevertheless, contained the greater percentage of water.

General discussion

Various views have been held as to the relation between transpiration and the production of plant substance, or the influence of these processes upon each other. As early as 1850, LAWES[14] expressed the belief that although the whole subject was as yet a problem, a certain relationship existed between evaporation and rapidity of growth, in that the comparative rate of evaporation of water to some extent indicated the comparative activity of the processes of the plants. He was too cautious an investigator, however, to conclude more than that his experiments indicated some definite relationship between the passage of water through the plant and the production of dry matter. A somewhat similar idea was expressed by FITTBOGEN.[15] HELLRIEGEL[16] in discussing this subject pointed out that, although the curves of growth and of transpiration follow the same general course, they are never parallel or coincident. He considered the dry substance produced merely as a convenient empirical basis from which to reckon the water-utilization of plants. As a result of his experiments, which how-

[13] This fact should be taken into consideration in the curing of shade-grown tobacco.

[14] LAWES, J. B., Experimental investigation into the amount of water given off by plants during their growth; especially in relation to the fixation and source of their various constituents. Jour. Hort. Soc. London 5:38–63. 1850.

[15] FITTBOGEN, J., Altes und Neues aus dem Leben der Gerstenpflanze. Landw. Vers.-Stationen 13:81–136. 1871.

[16] HELLRIEGEL, H., *op. cit.* pp. 622–623. 1883.

ever are open to criticism, he concluded that transpiration had no effect on the production of plant substance.[17]

A somewhat unusual standpoint was taken by SORAUER,[18] who regarded transpiration not merely as a mechanical process, but as a physiological function in the sense that it depends upon other physiological processes of the plant. According to him, outer factors do not influence transpiration directly, but only through their action on other functions of the plant.

A relation not less intimate, but in its nature the converse of that conceived by SORAUER, is that which KOHL[19] believed to exist between transpiration and assimilation. He described the influence of transpiration upon assimilation essentially as follows: A rapidly transpiring plant receives, by means of the transpiration stream, a greater abundance of mineral nutrients, and is thereby enabled to produce more organic matter than a plant with lower transpiration. It should be said that KOHL'S assumption was based purely on anatomical observations and not on comparative quantitative determinations. Increased transpiration does not necessarily bring about a greater abundance of mineral matter in plants.[20] A close correlation between transpiration and growth has recently been observed also by LIVINGSTON[21] in wheat seedlings during the early stages of their development.

Although in general the conclusion derived from the work of these authors is that transpiration and assimilation are correlated or at most that transpiration has no influence on production, experiments leading to an opposite conclusion are not wanting.

As early as 1869 SCHLOESSING[22] found that a tobacco plant growing under a shaded bell jar produced more dry leaf substance

[17] HELLRIEGEL, H., *op. cit.* pp. 461–501.

[18] SORAUER, P., Der Einfluss der Luftfeuchtigkeit. Bot. Zeit. **36**:1–13, 17–25. 1878; also Studien über Verdunstung. Forschungen Gebiete Agrikultur-Physik. **3**:351–490. 1880.

[19] KOHL, F. G., Die Transpiration der Pflanzen. pp. 90–116. 1886.

[20] HASSELBRING, H., The relation between the transpiration stream and the absorption of salts. BOT. GAZ. **57**:72, 73. 1914. A complete account of this work will appear later.

[21] LIVINGSTON, B. E., Relation of transpiration to growth in wheat. BOT. GAZ. **40**:178–195. 1905.

[22] SCHLOESSING, TH., Végétation comparée du tabac sous gloche et à l'air libre. Ann. Sci. Nat. Bot. V. **10**:366–369. 1869.

than plants grown in the open; but this experiment is open to several objections, not the least of which is that only the leaves were taken into consideration.

TSCHAPLOWITZ,[23] who gave considerable attention to the effect of transpiration on production, found in many of his experiments an increased production of dry substance as the result of decreased transpiration. From a consideration of these results in connection with those of others,[24] who according to him have found that an excessive depression of transpiration results in a lowering of assimilatory activity, he was led to the conclusion that there exists for plants an optimum magnitude of transpiration; and that if the transpiration exceeds, provided the turgor is always maintained, or falls short of the optimum, it is not possible for the plant to reach the maximum production of which it is innately capable. He regards transpiration as essentially a physical process, the magnitude of which may vary within wide limits without seriously disturbing the character of the processes in the plant, although there may be marked effects on the quantitative results of these processes, that is, on the quantity of the assimilatory products formed.

More decisive are the results of WOLLNY,[25] who grew plants of barley, vetch, alfalfa, flax, and potato under conditions giving three degrees of humidity, and found that with an increase in the degree of humidity there was an increase in the production both of the absolute quantity of fresh material and of dry matter. These experiments seem to indicate that a depression of transpiration results in an increase in the assimilatory activity of the plants.

In the experiments reported in this paper, the plants growing in the open transpired about 10 liters per plant or nearly 30 per cent more water than those grown under shade, yet in spite of this differ-

[23] TSCHAPLOWITZ, F., Über den Einfluss der Blattenflächen, des Zuwachses und der Temperature auf die Verdunstung der Pflanzen. Wiener Obst- und Garten-Zeitung **2**:127–132, 169–175, 222–228. 1877; Landw. Vers.-Stat. **23**:74. 1879 (abstract of address without title); Unters. ü. d. Einwirkung Wärme u. d. a. Formen d. Naturkräfte a. d. Vegetations-Erscheinungen. pp. 1–14. Leipzig, 1882; Gibt es ein Transpirations-Optimum? Bot. Zeit. **41**:352–362. 1883; Untersuchungen über die Wirkung klimatischen Faktoren auf das Wachsthum der Kulturpflanzen. Forschungen Gesamt Gebiet Agrikultur-Physik. **9**:117–145. 1886.

[24] The authorities are not given.

[25] WOLLNY, W., Untersuchungen über den Einfluss der Luftfeuchtigkeit auf das Wachsthum der Pflanzen. Inaug. Diss. Halle. 1898.

ence in transpiration the total quantity of dry substance produced was the same in both sets of plants. This fact suggests that transpiration in itself, or the mere passage of water through the plant, has no influence on assimilatory activity provided the water supply does not fall below a certain minimum required to maintain the turgor of the cells.[26]

There is another factor, however, to be taken into consideration in the discussion of the effect of transpiration on assimilation in these experiments. This factor is the reduced illumination to which the plants under cheese-cloth were subjected. The work of many investigators[27] has shown that for many plants in northern latitudes light can be considerably reduced without reducing the assimilatory activity.[28] An explanation of this fact is furnished by BLACKMAN and MATTHAEI,[29] who believe that under natural conditions leaf temperature and the partial pressure of carbon dioxide

[26] See footnote 12.

[27] TIMIRIAZEFF, C., The cosmical functions of the green plants. Proc. Roy. Soc. **72**:424–461. *pls. 3.* 1904.

BROWN, H. T., and ESCOMBE, F., Researches on some of the physiological processes of green leaves, with special reference to the interchange of energy between the leaf and its surroundings. Proc. Roy. Soc. B **76**:29–111. 1905.

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LUBIMENKO, W., Production de la substance sèche et de la chlorophylle chez les végétaux supérieurs aux différentes intensités lumineuses. Ann. Sci. Nat. Bot. IX. **7**:321–415. 1908.

COMBES, R., Détermination des intensités lumineuses optima pour les végétaux aux divers stades de développement. Ann. Sci. Nat. Bot. IX. **11**:75–249. 1910.

ROSÉ, E., Énergie assimilatrice chez les plants cultivées saus différents eclairements. Ann. Sci. Nat. Bot. IX. **17**:1–110. 1913.

SHANTZ, H. L., The effects of artificial shading on plant growth in Louisiana. U.S.D.A., Bur. Pl. Industry, Bull. 279. 1913. In this paper the data refer to fresh weights of the plants.

[28] In this connection it is interesting to note that SHANDER attributes the beneficial effects of Bordeaux mixture other than those that can be ascribed to its action as a fungicide to the shading produced by the coating on the leaves. Such beneficial action occurs, however, only during bright weather; during cloudy weather the effect of shading is injurious. SHANDER, R., Über die physiologische Wirkung der Kupferntriolkalkbrühe. Landw. Jahrb. **33**:517–584. 1901; see also EWERT, R., Der wechselseitige Einfluss des Lichtes und der Kupferkalkbrühen auf den Stoffwechsel der Pflanze. Landw. Jahrb. **34**:233–310. *pls. 3.* 1905, and Weitere Studien über die physiologische und fungicide Wirkung der Kupferbrühen bei krautigen Gewächsen und der Johannisbeere. Zeitschr. Pflanzenkrank. **22**:257–285. 1912.

[29] BLACKMAN, F. F., and MATTHAEI, Miss G. L. C., A quantitative study of carbon-dioxide assimilation and leaf temperature in natural illumination. Proc. Roy. Soc. B **76**:402–460. 1905.

function as limiting factors for photosynthesis, while light is usually present in excess.

It is evident from the writer's experiments that the reduction of light did not result in a lowering of the total production of plant substance; nevertheless, the production for equal areas of leaf surface was lower in the shade leaves than in the sun leaves. The reduction in photosynthesis in the shade leaves was compensated by an increase in leaf area, so that total production was not diminished.

Although shading, and the conditions brought about thereby, had no influence on the total elaboration of dry substance, the distribution of dry substance was greatly affected. The distribution of the total dry matter among the various organs of the two sets of plants was as follows:

TABLE XI

	Leaves	Stems	Roots
Sun plants..........	40 per cent	36 per cent	24 per cent
Shade plants........	36 per cent	42 per cent	22 per cent

The proportion of material deposited in the roots was about the same in the two sets of plants, but the proportion deposited in the leaves was much greater for the sun plants than for the shade plants, although the area of the shade leaves was nearly one-third greater than that of the sun leaves. This condition is in accordance with the general observation that rapidly transpiring leaves are thicker and of firmer structure than leaves developed under conditions of lower transpiration; or, as conversely expressed by SORAUER,[30] of equal weights of fresh leaf substance that portion containing the greater percentage of dry matter transpires the more rapidly. The condition in the stems was the reverse of that in the leaves. In the shade plants the stems contained 42 per cent of the total dry matter of the plant, while in the sun plants only 36 per cent was deposited in the stems. It appears, therefore, that the shading exercises a distinct influence on the deposition of material in the stems and leaves, but that the influence affects the two organs

[30] SORAUER, P., *op. cit.* p. 391.

in an opposite manner; and that little or no influence is exerted on the deposition of material in the roots.

From a practical standpoint the reduced transpiration effected by the cheese-cloth shade is of importance in regions like Western Cuba, where, as has been stated, most of the tobacco is grown with the aid of hand irrigation; but important as is this direct saving of water, it is probably not so significant as the effect of the cheese-cloth shade in reducing the loss of moisture from the soil, and thus increasing the moisture content of the upper layers.[31] The importance of this effect is shown by the investigations of WOLLNY,[32] and of MITSCHERLICH,[33] and particularly by the long series of researches of VON SEELHORST[34] and his co-workers which show that the yield of crop increases with an increase of the degree of saturation at which the soil is maintained; according to MITSCHERLICH, even to complete saturation.

[31] STEWART found in Connecticut that the moisture content of the soil was always higher under the cheese-cloth than in the open ground. STEWART, J. B., *op. cit.* In the writer's experiments the control tanks under the shade lost respectively 3865, 3932, and 3698 cc.; while those in the open lost 4495, 4525, and 4549 cc. of water.

[32] WOLLNY, E., Untersuchungen über den Einfluss der Wachstums-Factoren auf das Productionsvermögen der Kulturpflanzen. Forsch. Agrik.-Physik. **20**:53–109. 1897–1898.

[33] MITSCHERLICH, E. A., Das Wasser als Vegetationsfactor. Landw. Jahrb. **42**:701–717. 1912.

[34] TUCKER, M., und VON SEELHORST, C., Der Einfluss, welchen der Wassergehalt und der Reichtum des Bodens auf die Ausbildung der Wurzeln und der oberirdischen Organe der Haferpflanze ausüben. Jour. Landswirtsch. **46**:52–63. 1908.

VON SEELHORST, C., Über den Wasserverbrauch der Haferpflanze bei verschiedenen Wassergehalt und bei verschiedener Düngung des Bodens. *Ibid.* **47**:369–378. 1899.

———, Neuer Beitrag zur Frage des Einflusses des Wassergehalts des Bodens auf die Entwicklung der Pflanzen. *Ibid.* **48**:165–177. *pls. 2.* 1900.

VON SEELHORST, C., GEORGES, N., und FAHRENHOLZ, F., Einfluss des Wassergehaltes und der Düngung des Bodens auf die Produktion und die Zuzammensetzung von Futterpflanzen, italienisches Raigras u. Klee. *Ibid.* **48**:265–286. 1900.

VON SEELHORST, C., und GEORGES, N., Der Einfluss der Düngung und des Wassergehaltes des Bodens auf den Bau und auf die Zuzammensetzung der Gerstenpflanze resp. des Gerstenkornes. *Ibid.* **48**:325–347. 1900.

VON SEELHORST, C., und FRECKMANN, W., Der Einfluss des Wassergehaltes des Bodens auf die Ernten und die Ausbildung verschiedener Getreide-Varietäten. *Ibid.* **51**:253–269. 1903.

VON SEELHORST, C., Die Bedeutung des Wassers im Leben der Kulturpflanzen. *Ibid.* **59**:259–291. 1911.

Conclusions

Under the climatic conditions of Western Cuba the transpiration of tobacco plants grown in the open ground is nearly 30 per cent greater than the transpiration of plants grown under the cheese-cloth shade commonly used for shading tobacco in that region (fig. 1). The transpiration per unit area of leaf surface is nearly twice as great in the sun plants as in the shade plants.

The shading of tobacco plants by this grade of cheese-cloth does not seem to result in a diminished production of total plant substance by the shaded plants as compared with other like plants not shaded. Since, however, the leaves of the shade-grown plants have a much greater total area than those of plants grown in the open, it is evident that the quantity of plant material elaborated per unit of leaf area is greater in the plants grown in the open.

Although the total production of dry plant substance is not influenced in any marked degree by the cheese-cloth shade, the distribution of this substance is affected in such a manner that in the shade-grown plants relatively less material is deposited in the leaves and more in the stems than in the corresponding organs of the plants grown in full light. No evident influence is exerted on the deposition of material in the roots.

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